MBMW (Multi-Beam Mask Writer) development for the 11nm hp technology node

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Tokyo Conference Center Shinagawa
June 26, 2012

IMS Nanofabrication AG, Vienna, Austria

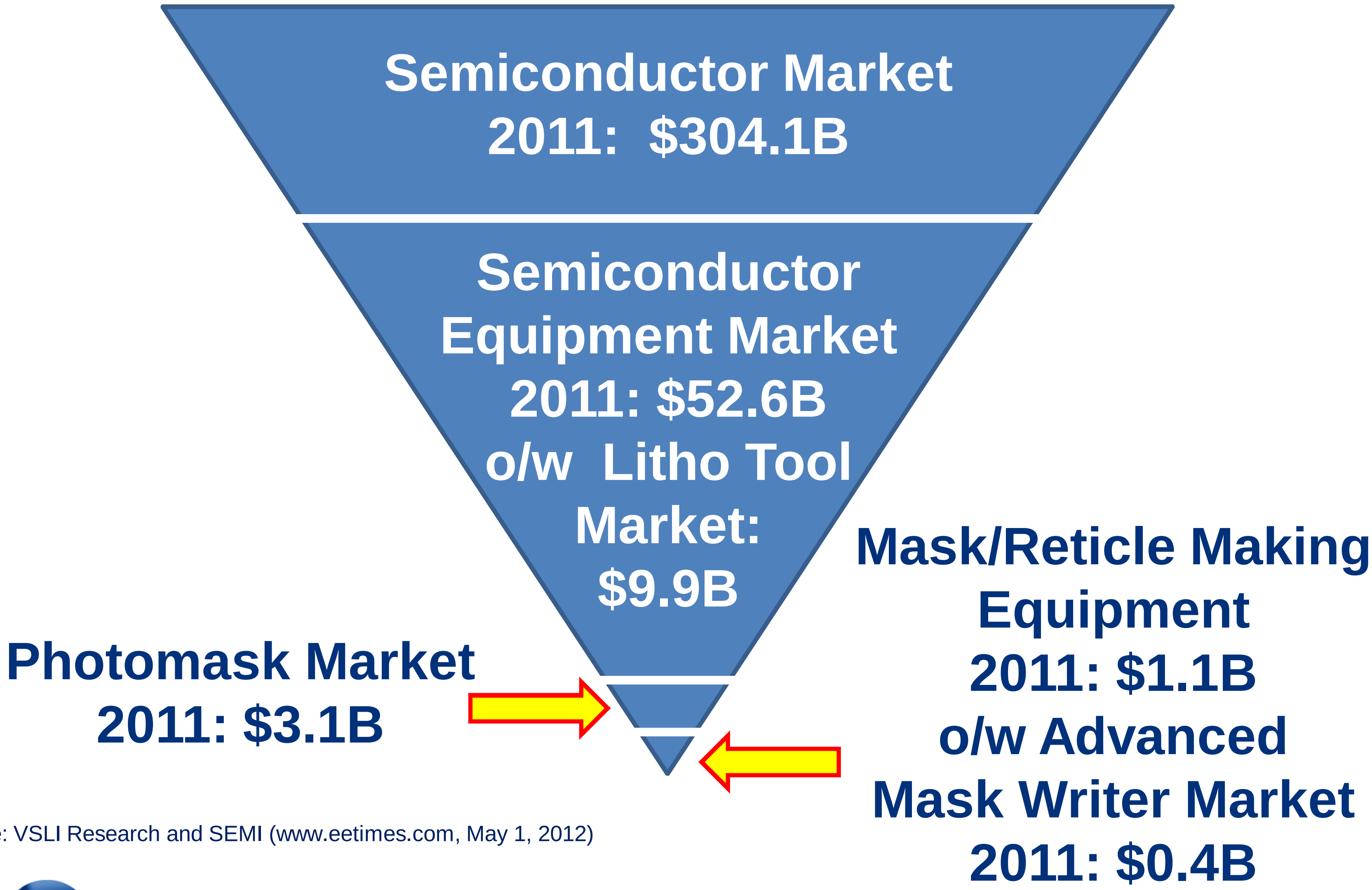
IMS Nanofabrication AG ("IMS") was founded in Dec 2006. IMS has ca. 60 coworkers, in particular engineers and physicists.

Share holders of IMS are private Austrian investors, and as announced (Dec 7 / 2011 press release), INTEL Capital and PHOTRONICS.

IMS is focused on the development of a 50keV electron multi-beam mask writer, coined **eMET** – **e**lectron **M**ask **E**xposure **T**ool.

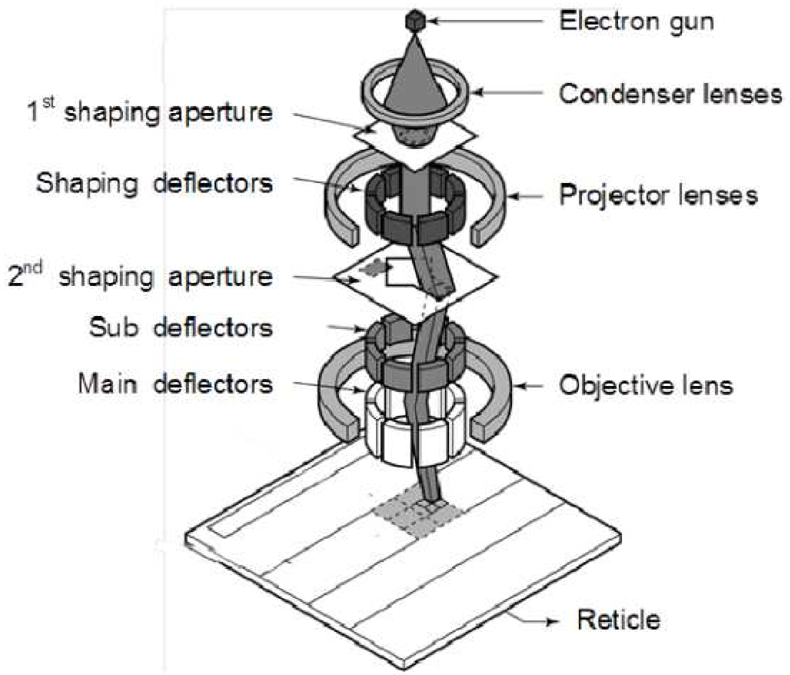
For eMET development, a Collaboration was formed by DNP, IMS, INTEL and PHOTRONICS (Jan 23 / 2012 press release).

Advanced Mask Writer: key importance for SC industry



Source: VSLI Research and SEMI (www.eetimes.com, May 1, 2012)

electron VSB (Variable Shaped Beam) Mask Writer

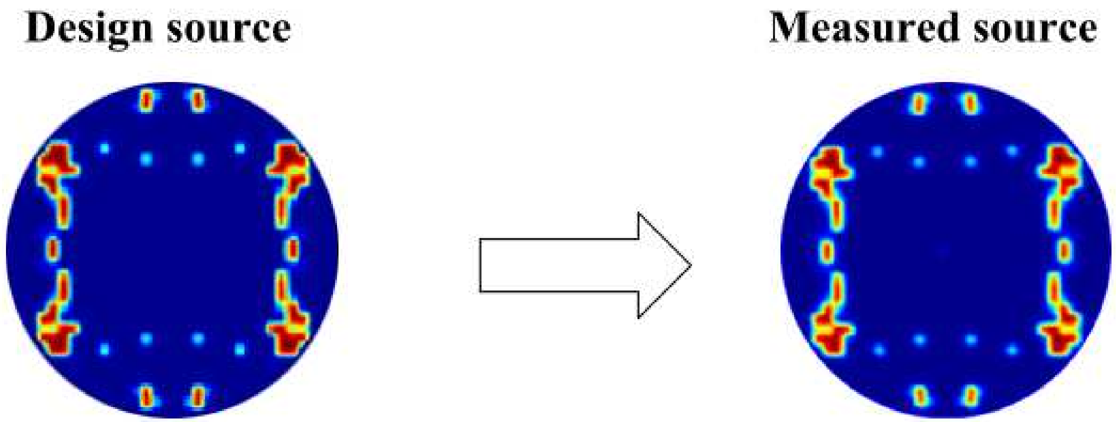


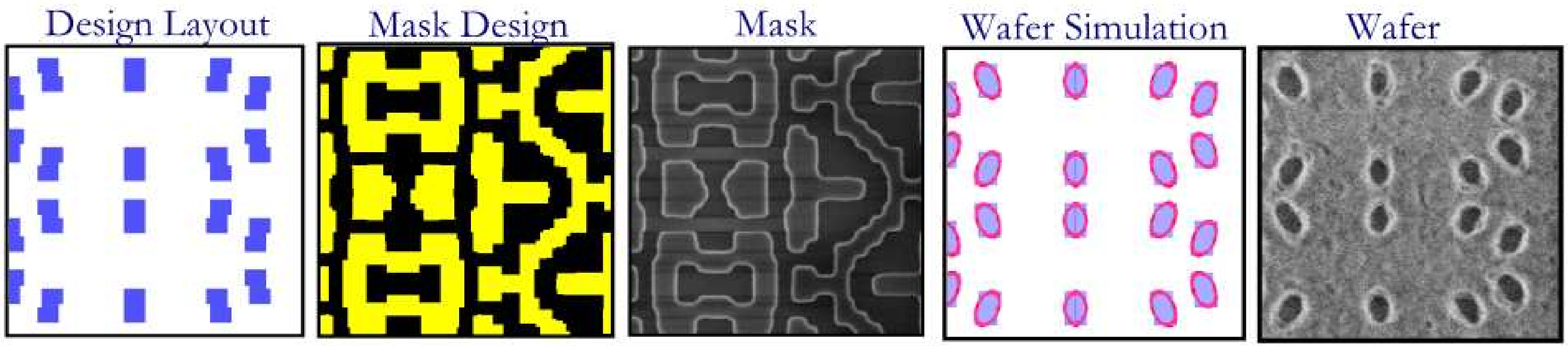
Electron optical system of EBM-8000

Model	EBM-8000
Acceleration voltage	50 kV
Current density	400 A/cm^2
Cathode	LaB_6
Maximum beam size	0.35 μm square
Main deflection field size	120 μm x 180 μm
Sub deflection field size	10 μm square
Input data format	VSB-12
Data address unit	0.1 nm ~ 100 nm (0.1 nm increment)

Source: Suzuki Yoshitake, et al., NuFlare, SPIE Photomask BACUS 2011

SMO – Source Mask Optimization

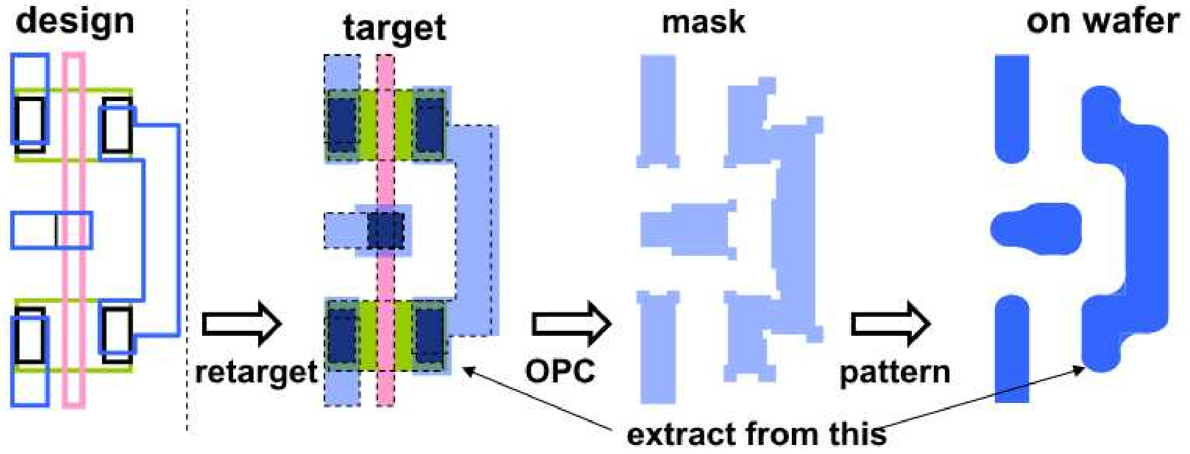




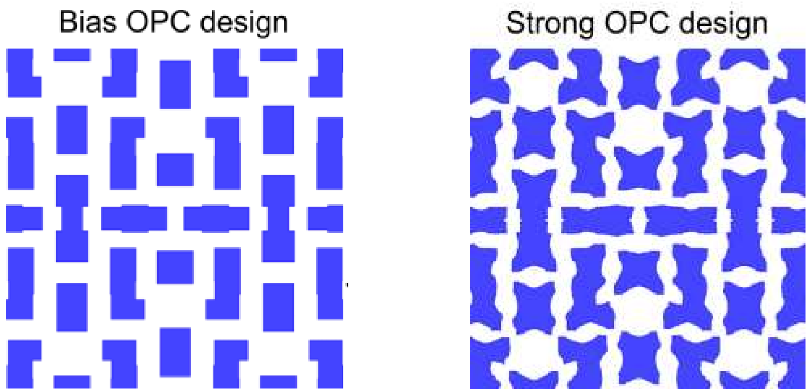
Source: Kaifai Lai, IBM, MNC 2009

Computational Lithography: OPC

OPC – Optical Proximity Correction



Source: Kaifai Lai, IBM, MNC 2009



⇨ **improved DOF**

Source: Naoya Hayashi, DNP, LithoVision 2012

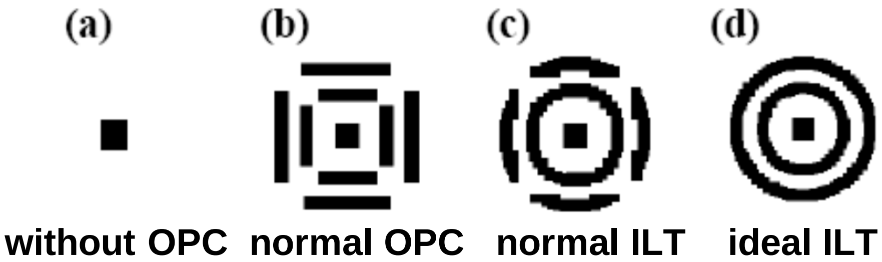
Computational Lithography: ILT

ILT – Inverse Lithography Technology

28nm

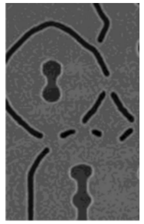
Courtesy : Samsung

Source: Aki Fujimura, eBeam Initiative luncheon, Photomask Japan 2012



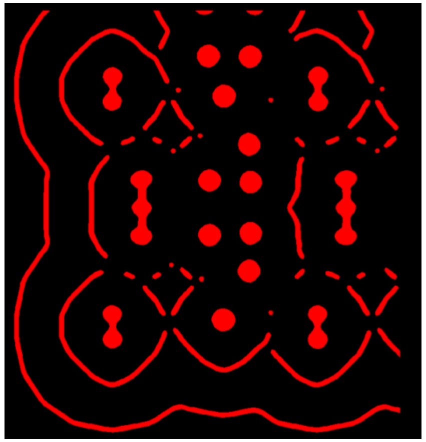
Source: Jin Choi et al., Samsung, Photomask Japan 2009

14nm



Courtesy : DNP

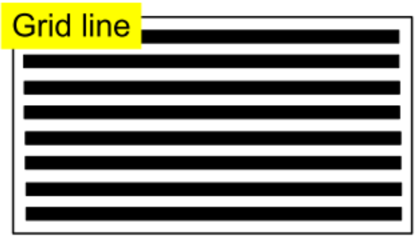
Source: Aki Fujimura, eBeam Initiative luncheon, Photomask Japan 2012

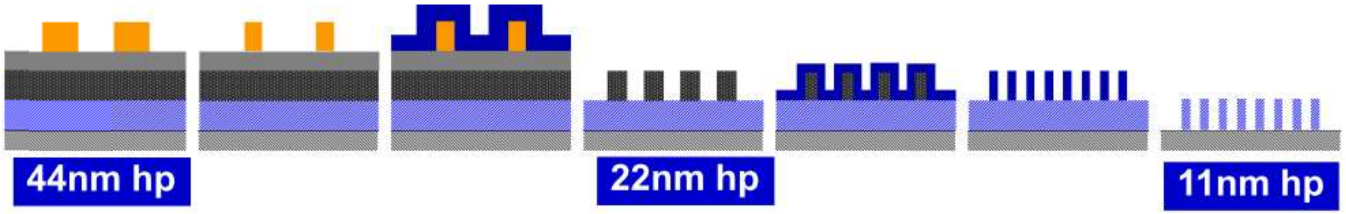


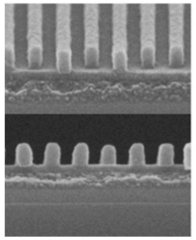
Source: Naoya Hayashi, DNP

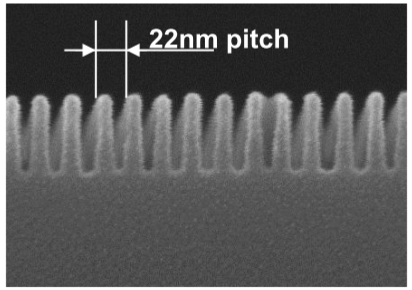
11nm hp Complementary Lithography

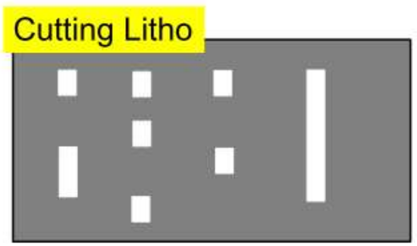
193i (193nm immersion) lithography with self-aligned Quadruple Patterning









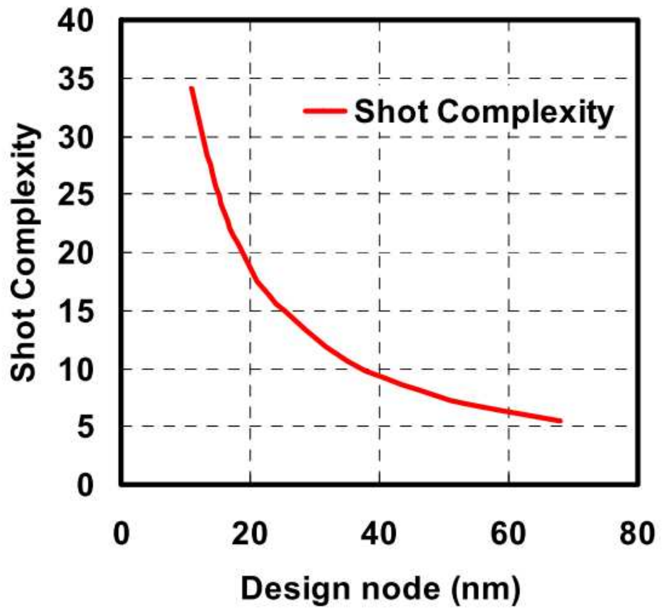


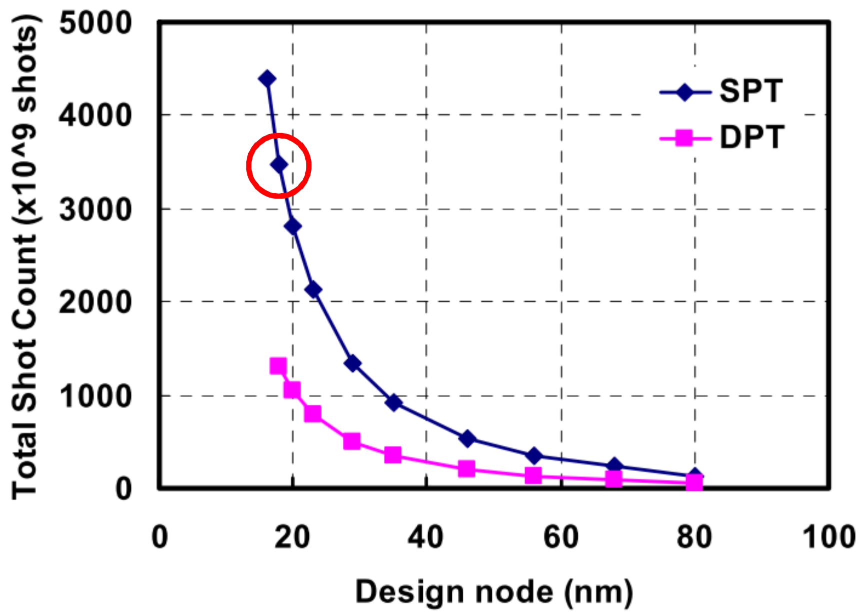
single exposure EUV lithography or **multiple exposures 193i lithography**

Source: Hidetami Yaetashi, TEL, 2011 SEMATECH international Symposium on Lithography Extensions

⇨ VSB Mask Write Time Explosion for sub-20nm nodes

SPT…single patterning
DPT…double patterning





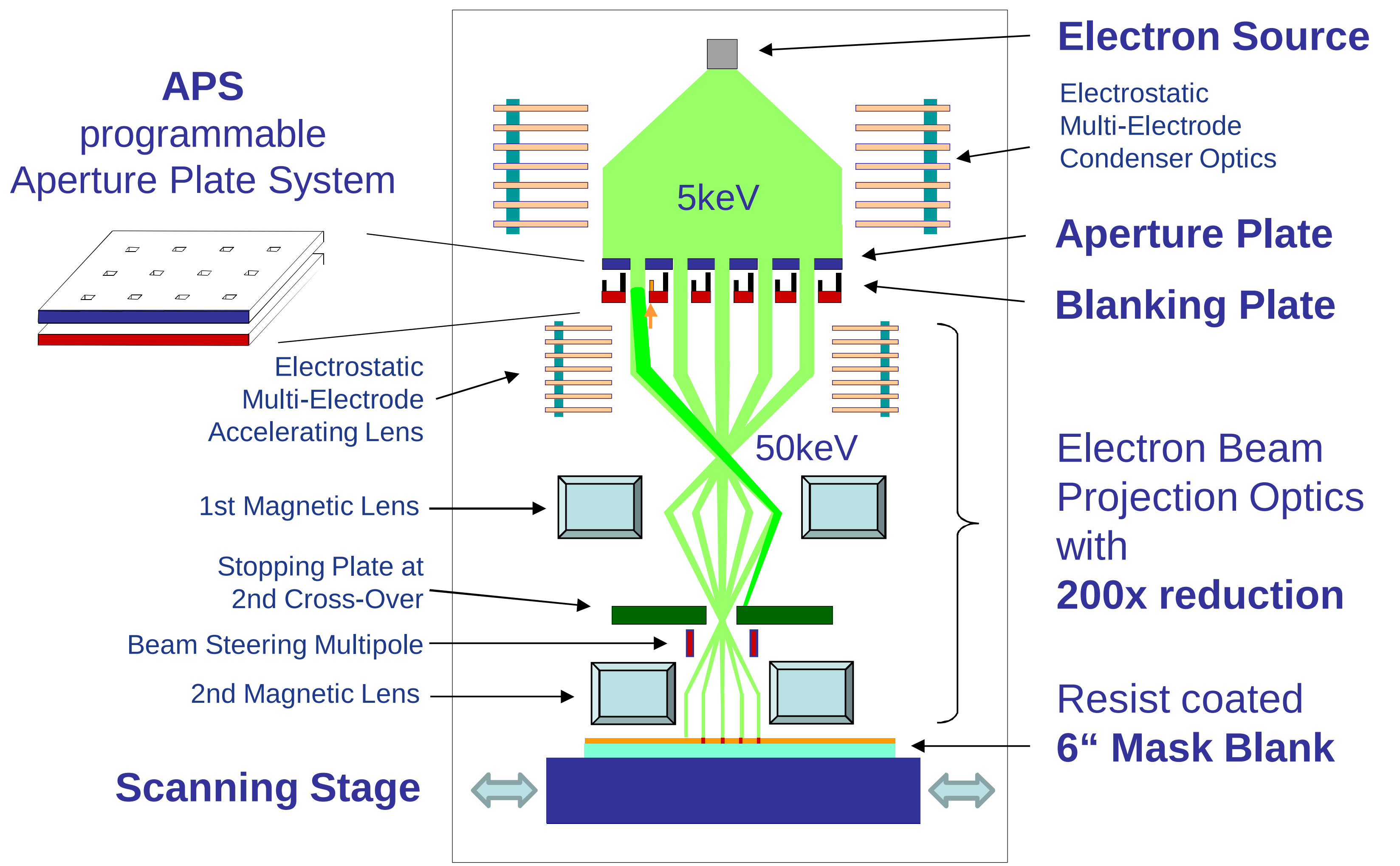
"The predicted writing time for layout with maximum total shot count is **58 hours** for **18nm node** with **400 A/cm^2**"

Source: Sang Hee Lee, Jin Choi, et al., Samsung Electronics, Photomask Japan 2010

Electron Multi-Beam Mask Writer for 11nm hp and below

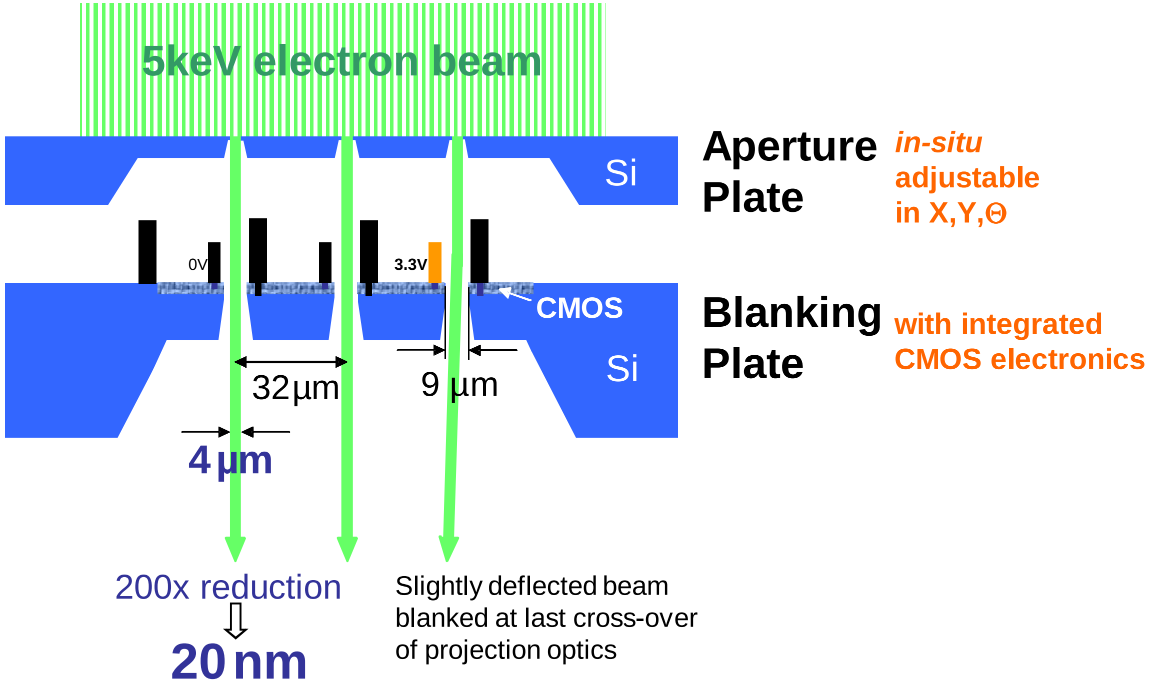
- 193nm water immersion (193i) lithography is extended to sub-20nm technology nodes, requiring SMO leading-edge masks with strong OPC and complex ILT patterns.
- EUV lithography at sub-20nm nodes will also require complex masks.
- Desired 10h (mandatory < 24h) mask writing times cannot be realized with VSB technology for the 11nm hp mask technology node and below.
- ⇨ **Multi-beam techniques are mandatory to meet industrial needs.**

eMET – electron Mask Exposure Tool



256k-APS (Aperture Plate System)

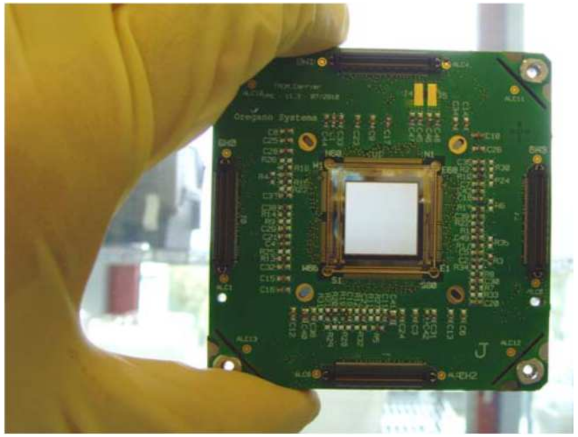
APS operated at - 45 kV

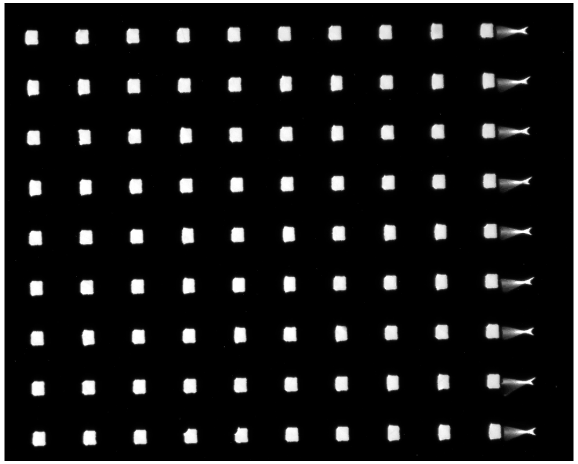


256k (k=1024) **= 262,144 programmable beams of**
20nm beam size and 50keV beam energy within
82µm x 82µm beam array field at
6" mask substrate

256k-APS (Aperture Plate System)

Fully operational 256k-APS installed in proof-of-concept tool (eMET POC)

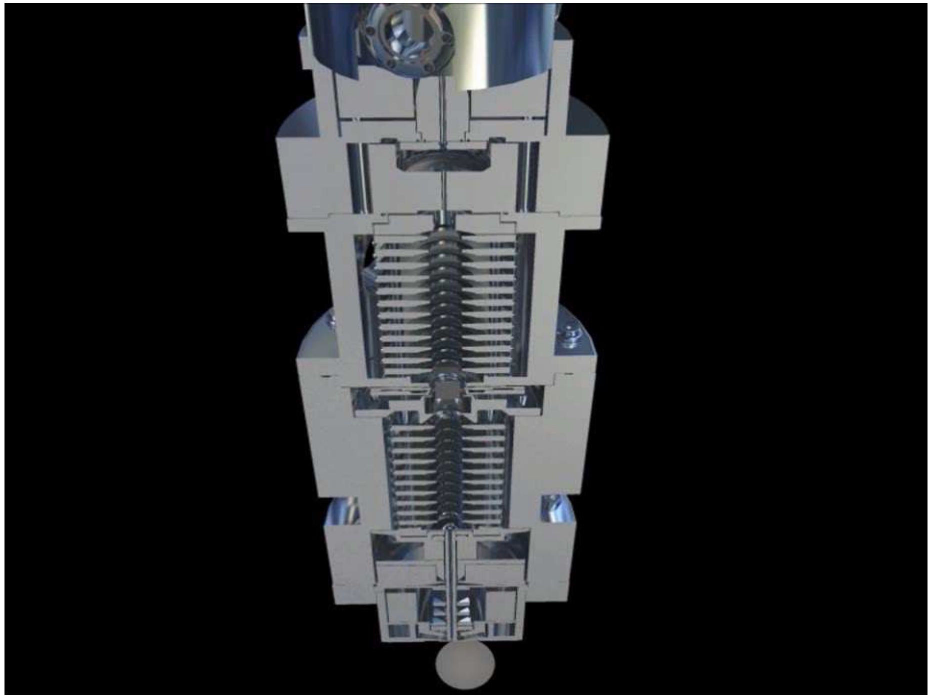




256k-APS	
# beams	262,144 (512x512)
Beam size	20nm (at substrate)
Beam array field	82µm x 82µm (at substrate)
Data rate	12.8 Gbps (max)

Proof-of-Concept electron Mask Exposure Tool

eMET POC

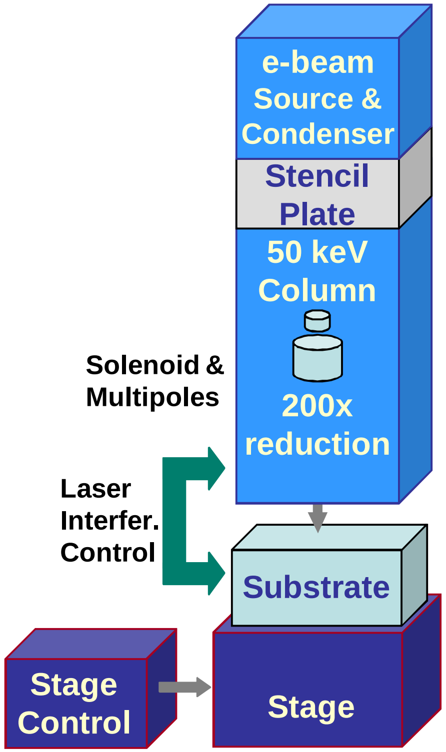


- ❒ Column designed for 11nm hp (8nm logic) node
- ❒ Column extendibility to 8nm hp and 6nm hp nodes

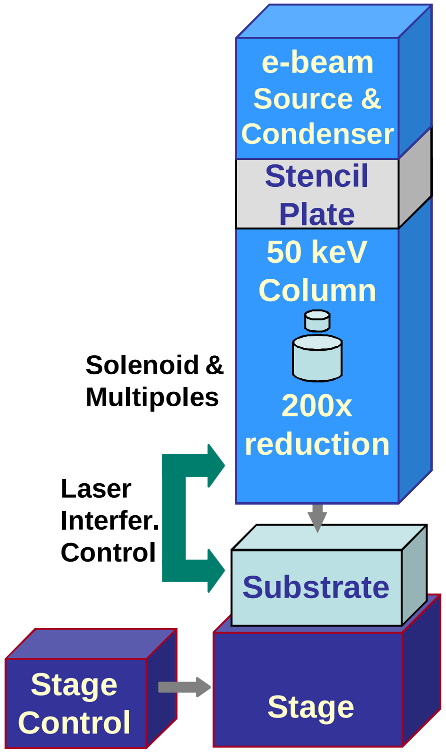
eMET POC Schedule

July 2011 September 2011

Beam On



Stationary stage exposures with Stencil Plate

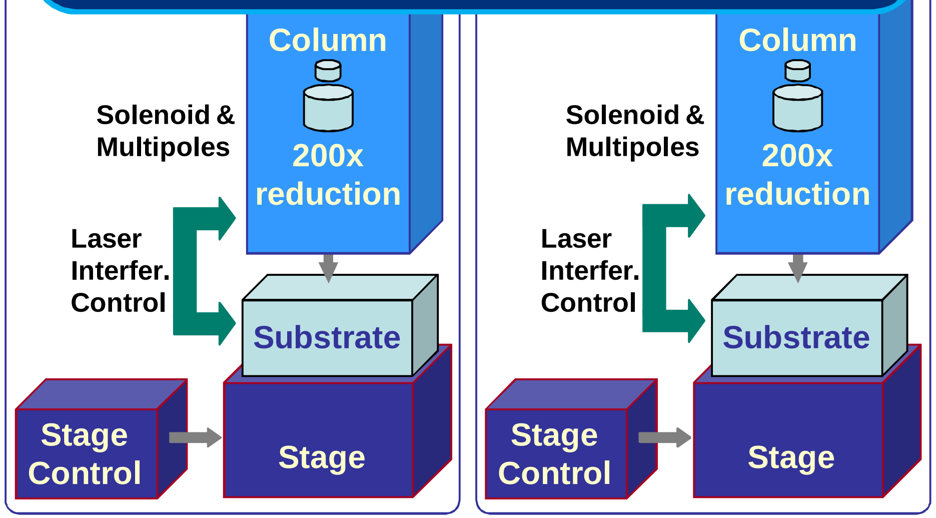


eMET POC Schedule

July 2011 September 2011

Predicted **5nm 1sigma blur** within **82µm x 82µm beam array field** confirmed by experiments:

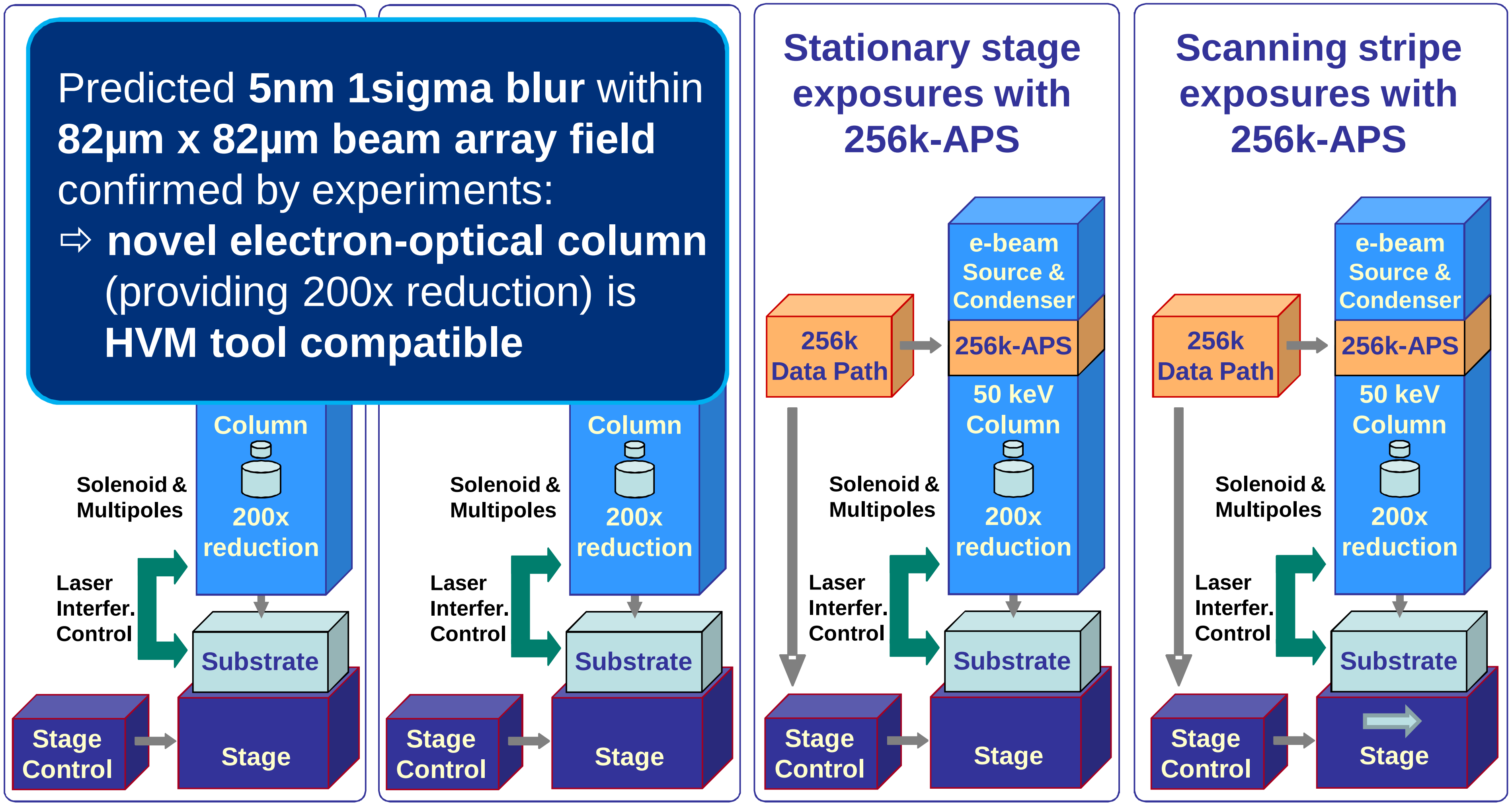
⇨ **novel electron-optical column** (providing 200x reduction) is **HVM tool compatible**



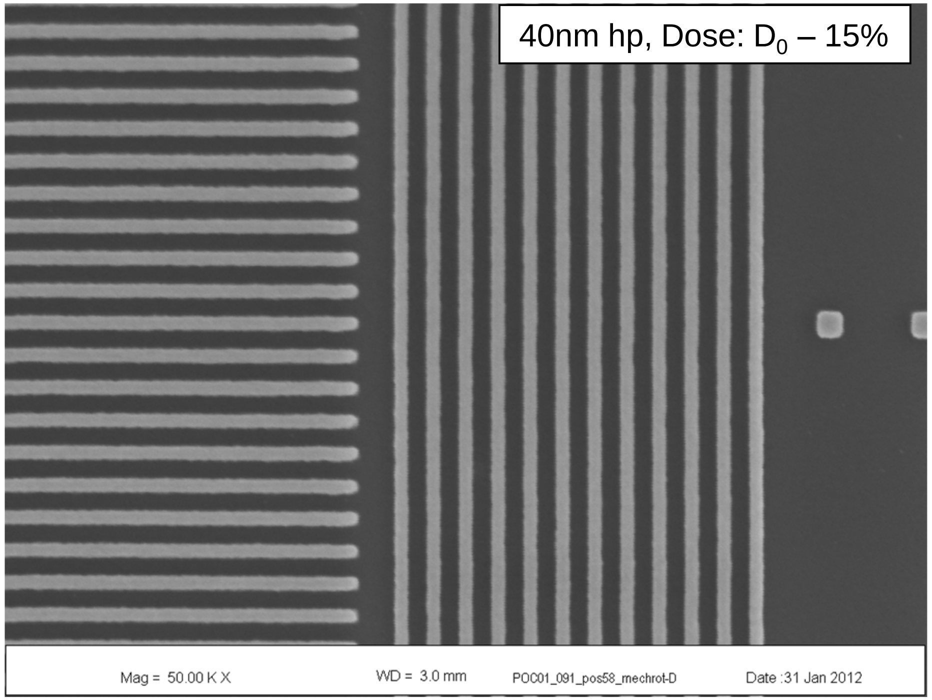
eMET POC Schedule

July 2011 | September 2011 | December 2011 | March 2012

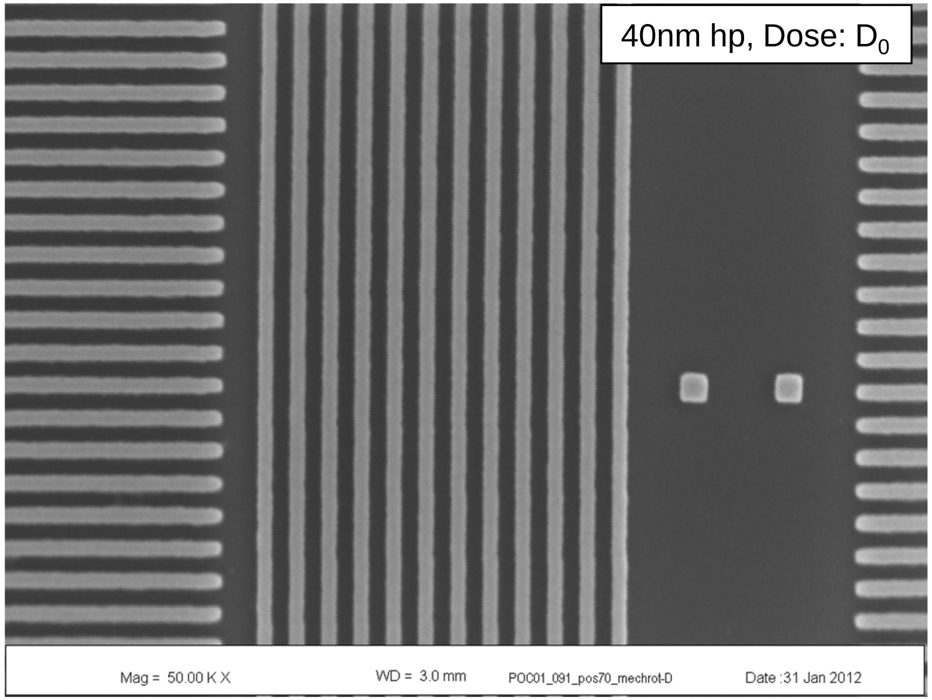
Predicted **5nm 1sigma blur** within
82µm x 82µm beam array field
confirmed by experiments:
⇨ **novel electron-optical column**
(providing 200x reduction) is
HVM tool compatible



eMET POC Resolution and Dose Latitude



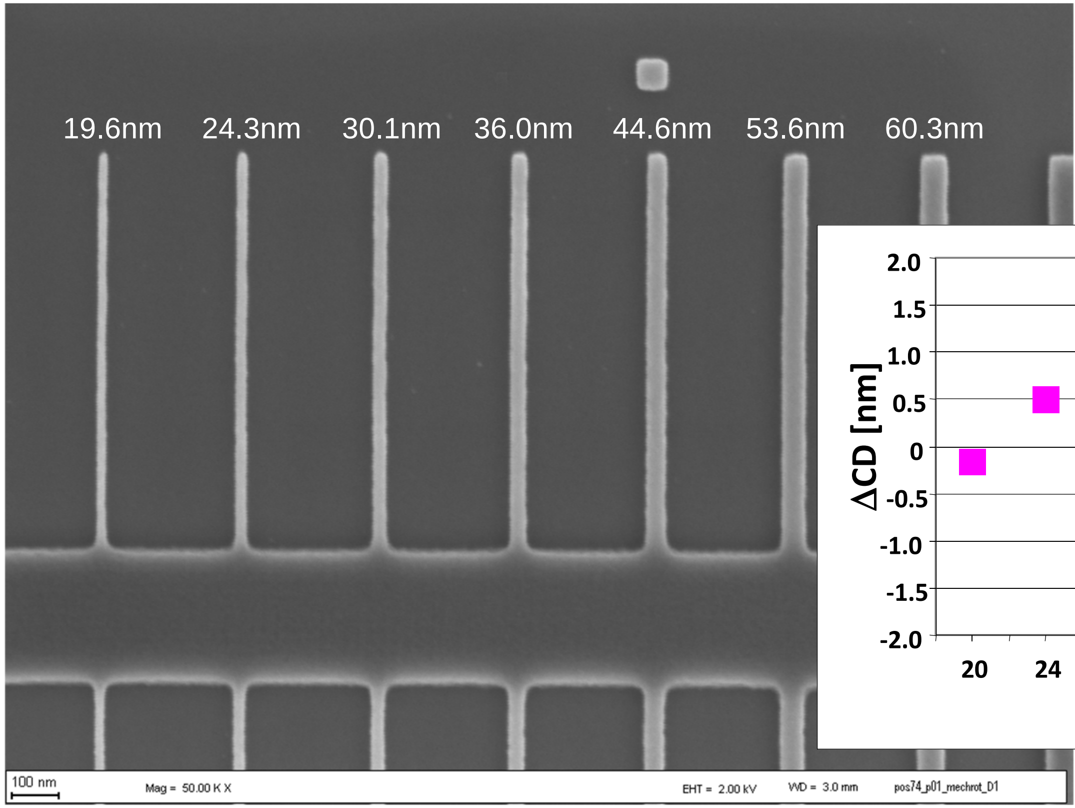
Measured CD: 34.7 nm @ 860 µC/cm² exposure dose



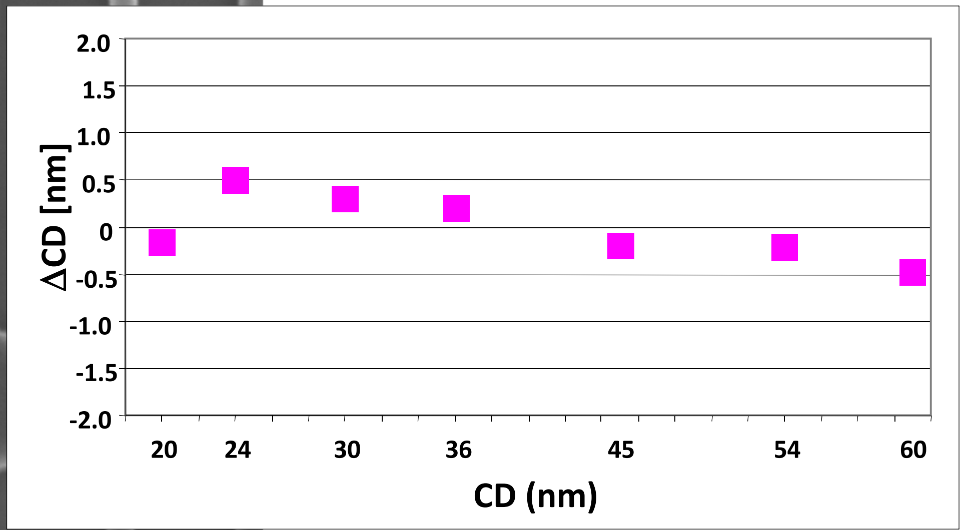
Measured CD: 38.2 nm @ 990µC/cm² exposure dose

ΔCD = 2.3 nm / +10% Dose

eMET POC Resolution: Iso Line & Linearity



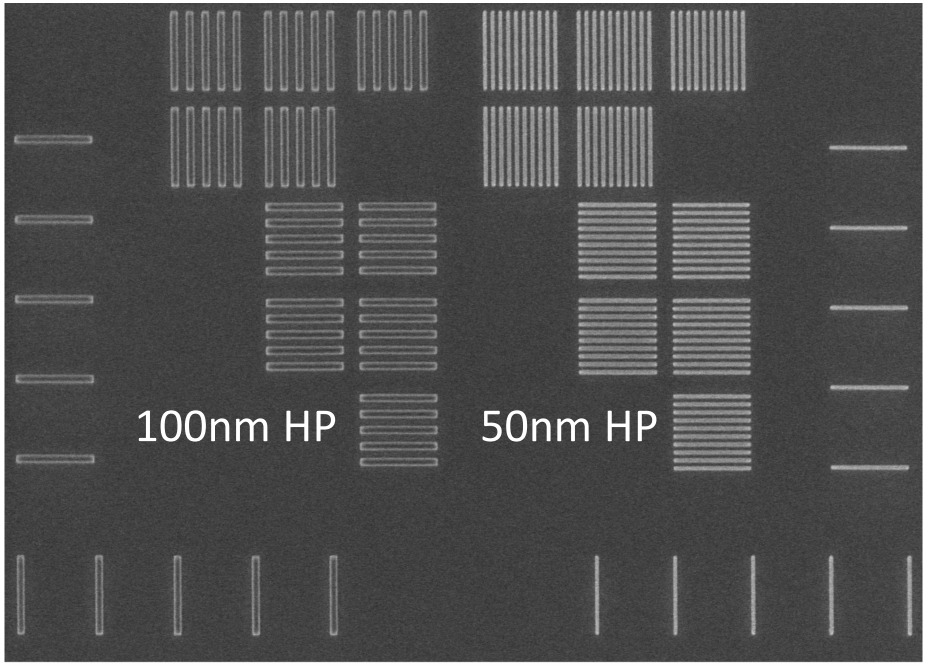
20nm iso-line printed



Iso-line linearity within ±0.5nm without corrections

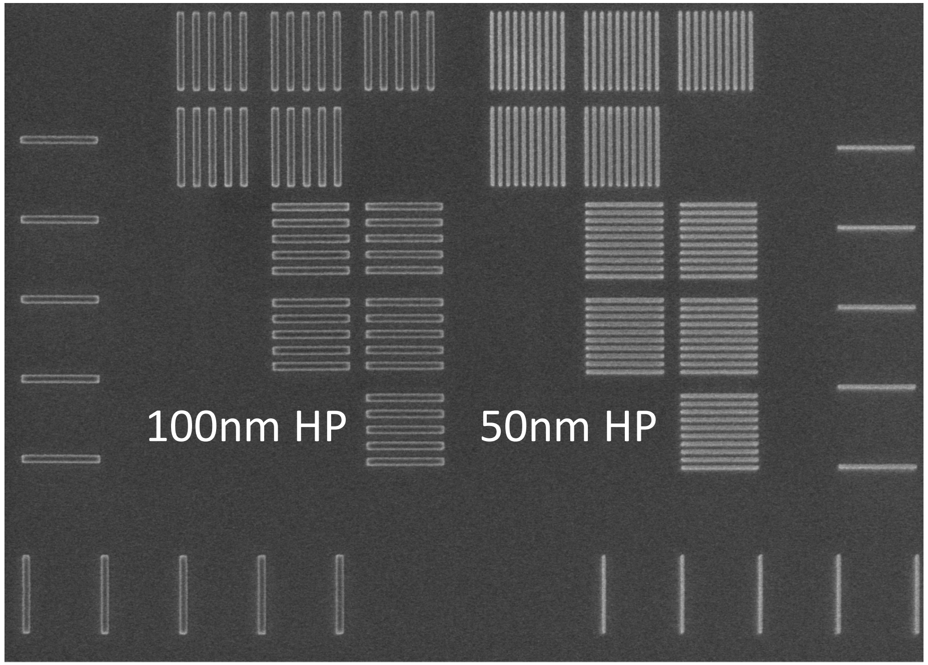
eMET POC Stationary Stage & Scanning Stripe Exposure

Stationary Stage Exposure



POC01_116_pos39_subF_mechrot, 10k, 2kV, WD3 — 3 µm

Scanning Stripe Exposure



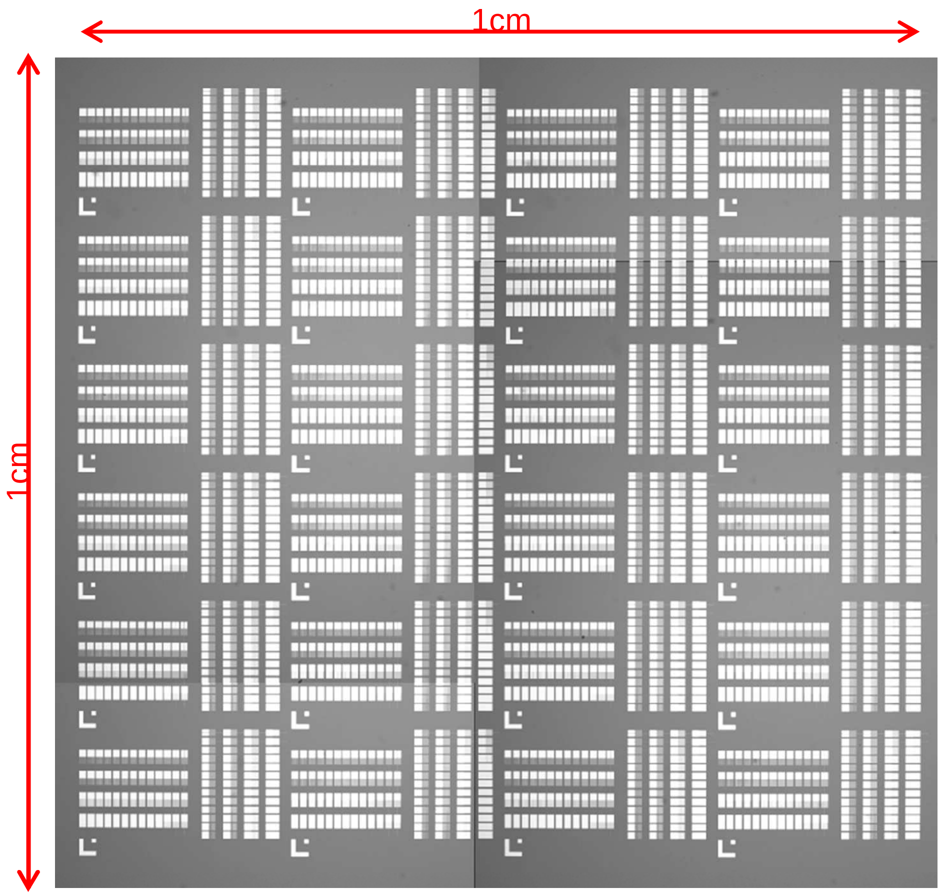
POC01_116_pos38_subF-I_mechrot, 10k, 2kV, WD3 — 3 µm

- No difference in resolution after having beam array scale and rotation adjusted

eMET POC Throughput

- 80nm pCAR
- $1cm^2$ printed in Double Grid multi-beam exposure mode
- Base dose: 72 µC/cm^2
- Max dose (incl. PEC): 103 µC/cm^2
- Current Density at substrate: 0.105 A/cm^2
- Write time / 1cm long stripe: 8.14s
  (stripe width: 81.92µm)
  ⇔ **stage velocity** **1.23mm/s**
- **Net write time $1cm^2$:** 17min
  (125 stripes w/o stage and
  datapath overhead)

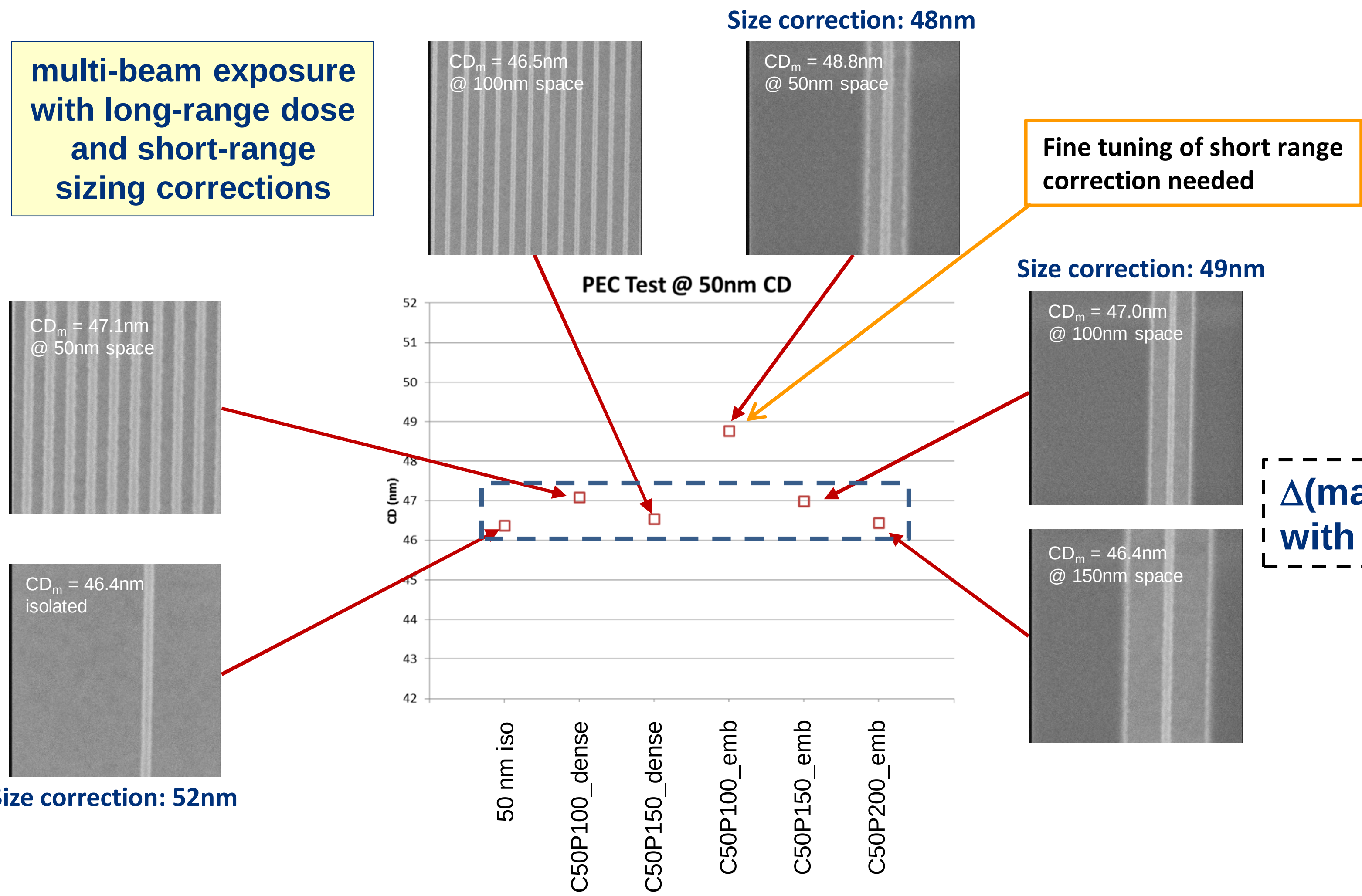
3.54cm^2/h



4 optical microscope images stitched together

electron multi-beam Proximity Effect Correction (PEC)

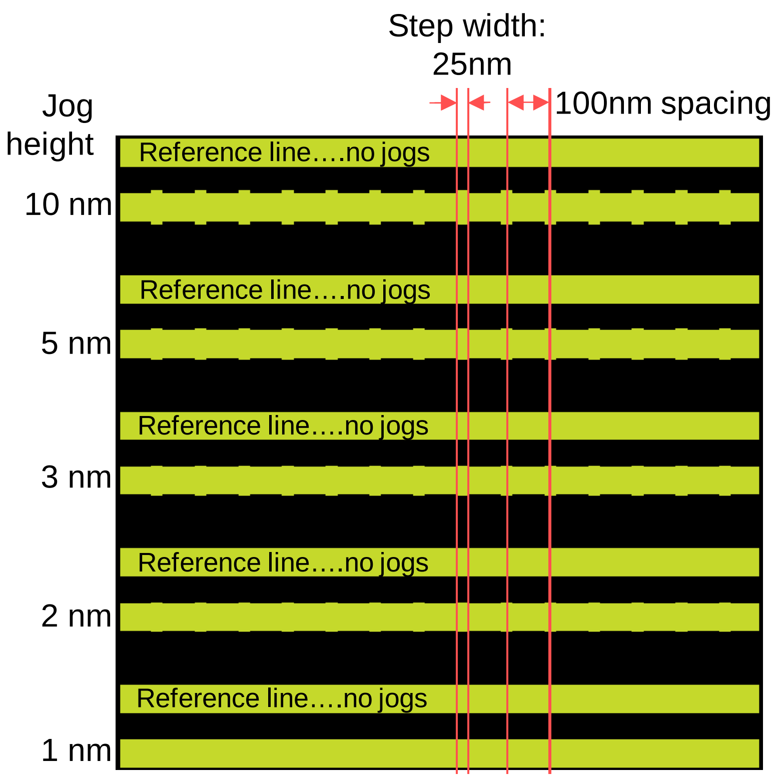
multi-beam exposure with long-range dose and short-range sizing corrections

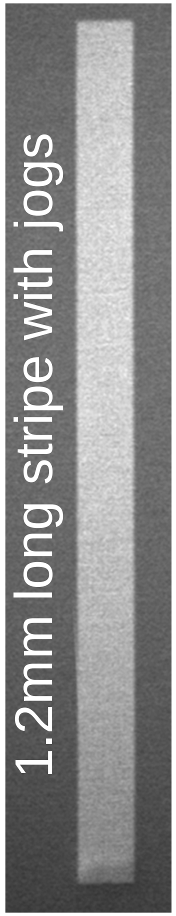


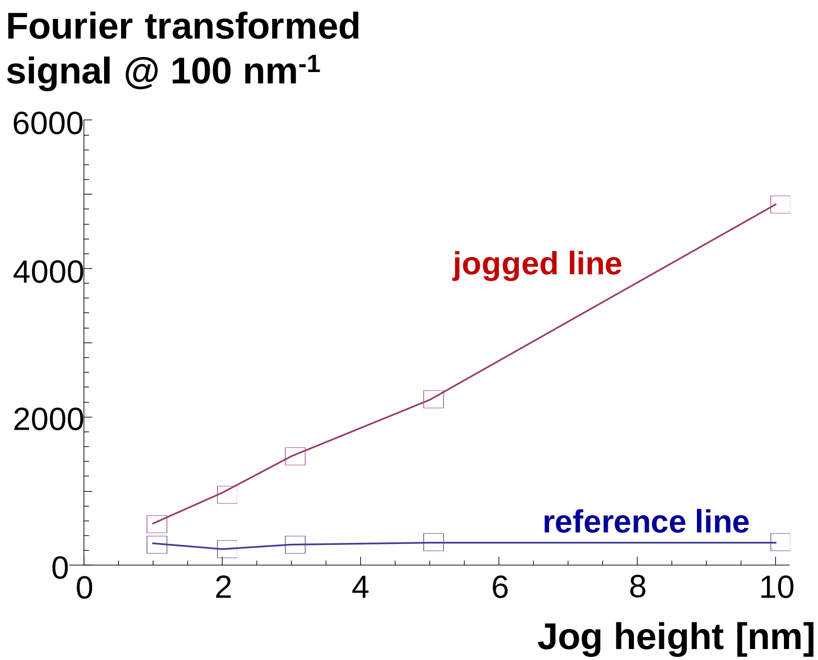
Δ(max) = 0.7nm with PEC

Scanning Stripe exposure of OPC test patterns: Jogs

Result of 12 positions measured along 1.2mm OPC stripe @ 100µm interval.

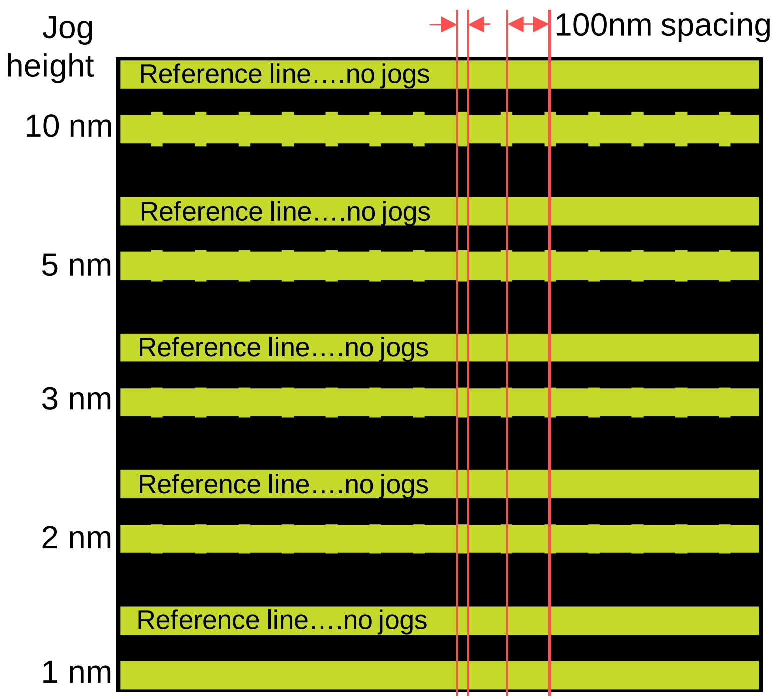


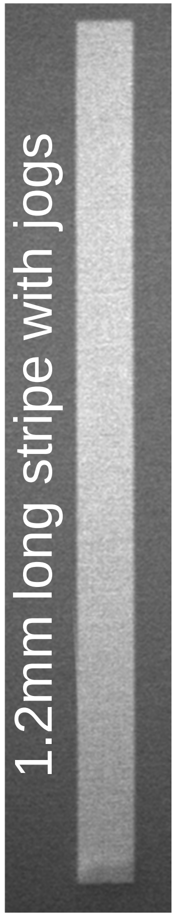




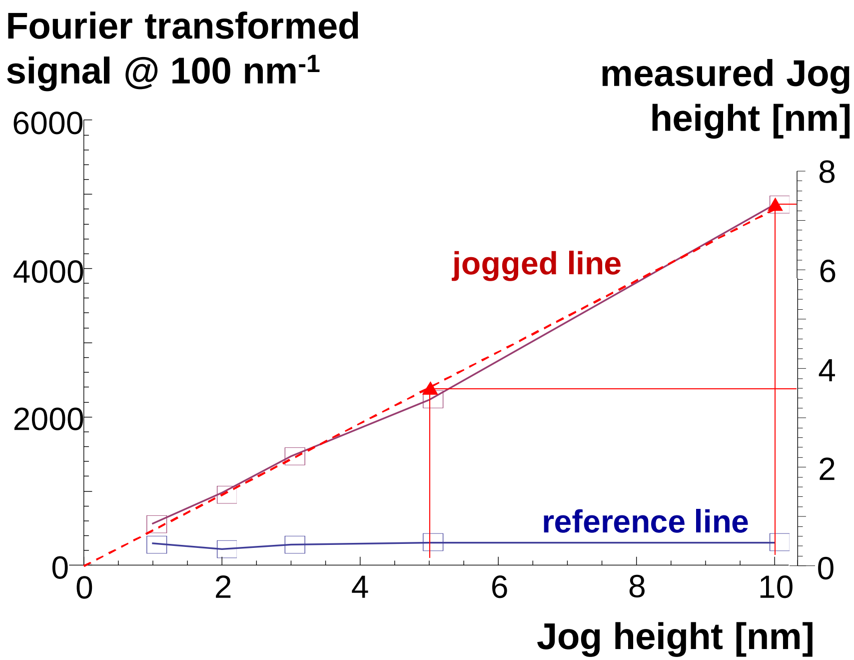
❒ 1nm Jogs resolved in scanning stage exposure mode

Scanning Stripe exposure of OPC test patterns: Jogs





Result of 12 positions measured along 1.2mm OPC stripe @ 100µm interval.

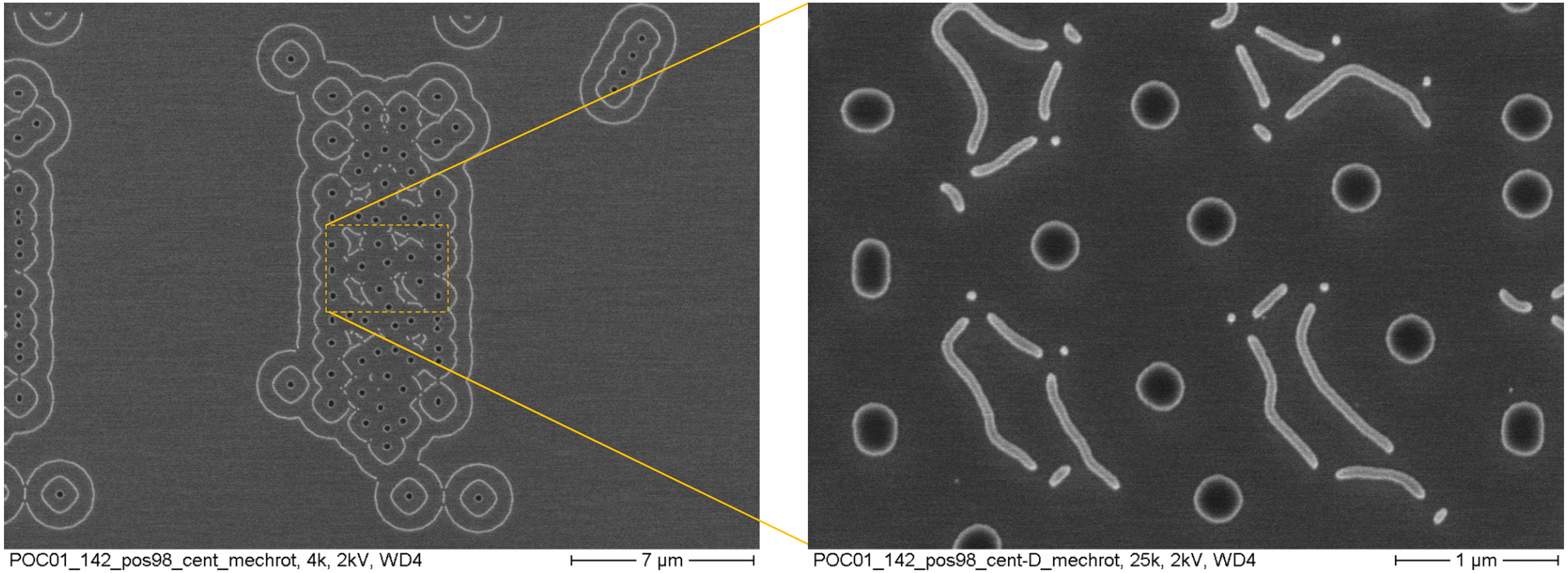


❒ 1nm Jogs resolved in scanning stage exposure mode

Scanning Stripe exposure of ILT device test patterns

ILT test pattern design: DNP

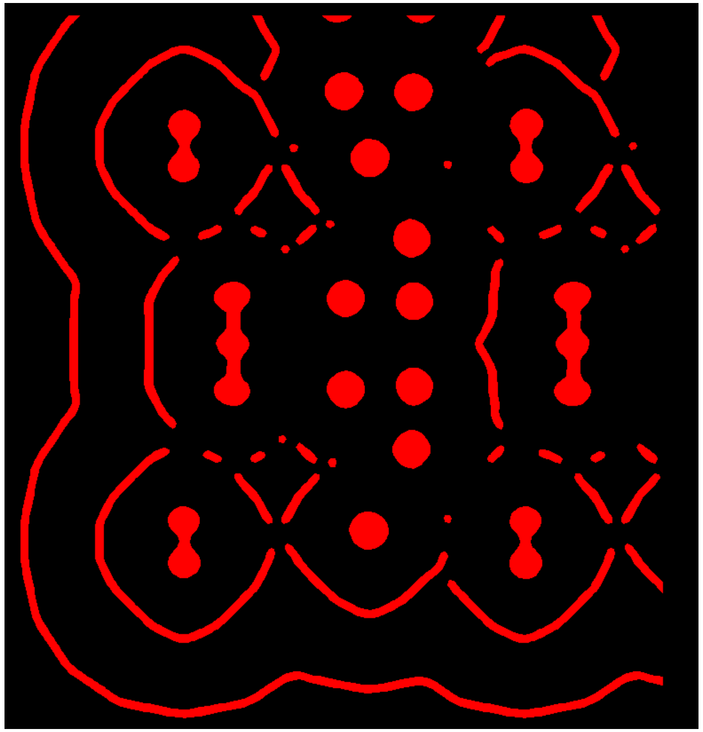
50nm dots, 75nm lines



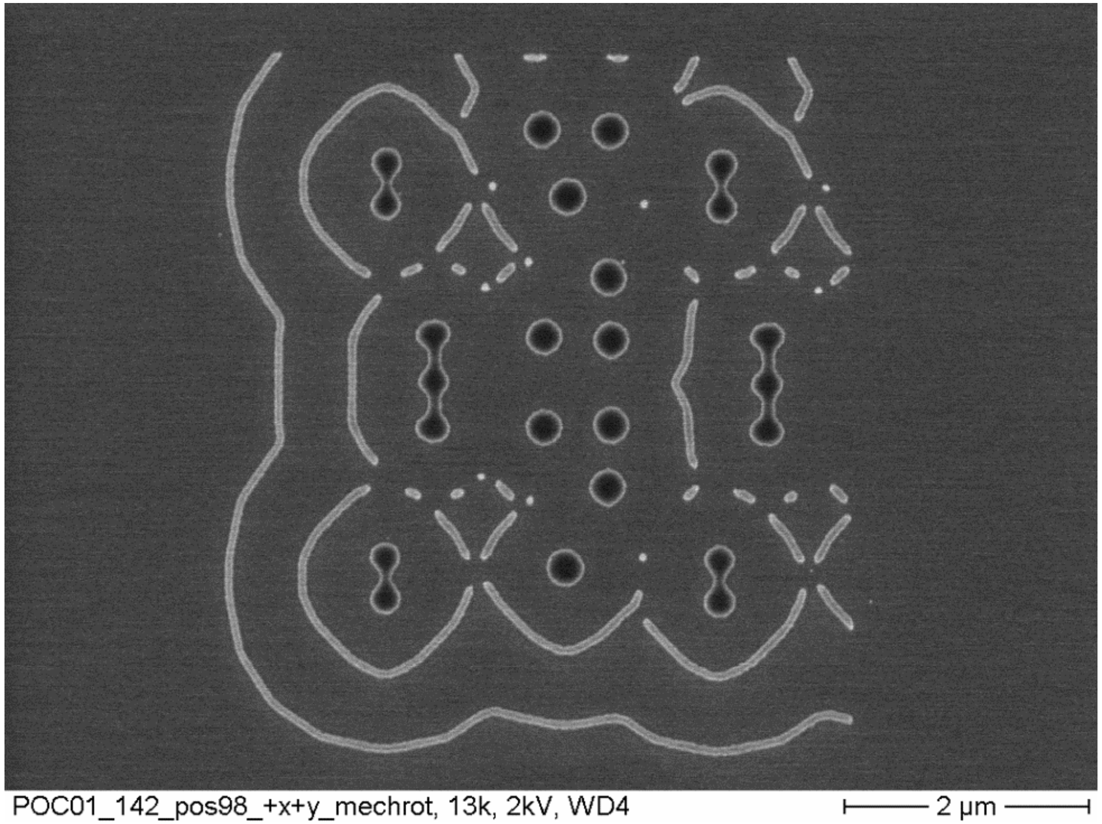
❒ Multi-Beam exposure without loss of TPT

Scanning Stripe exposure of ILT device test patterns

ILT test pattern design: DNP

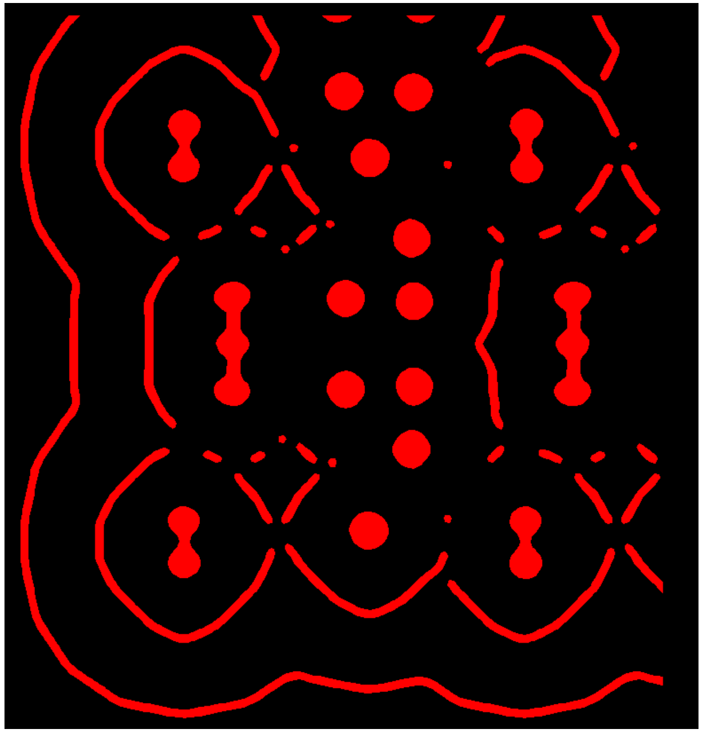


ILT: 60nm dots, 60nm lines

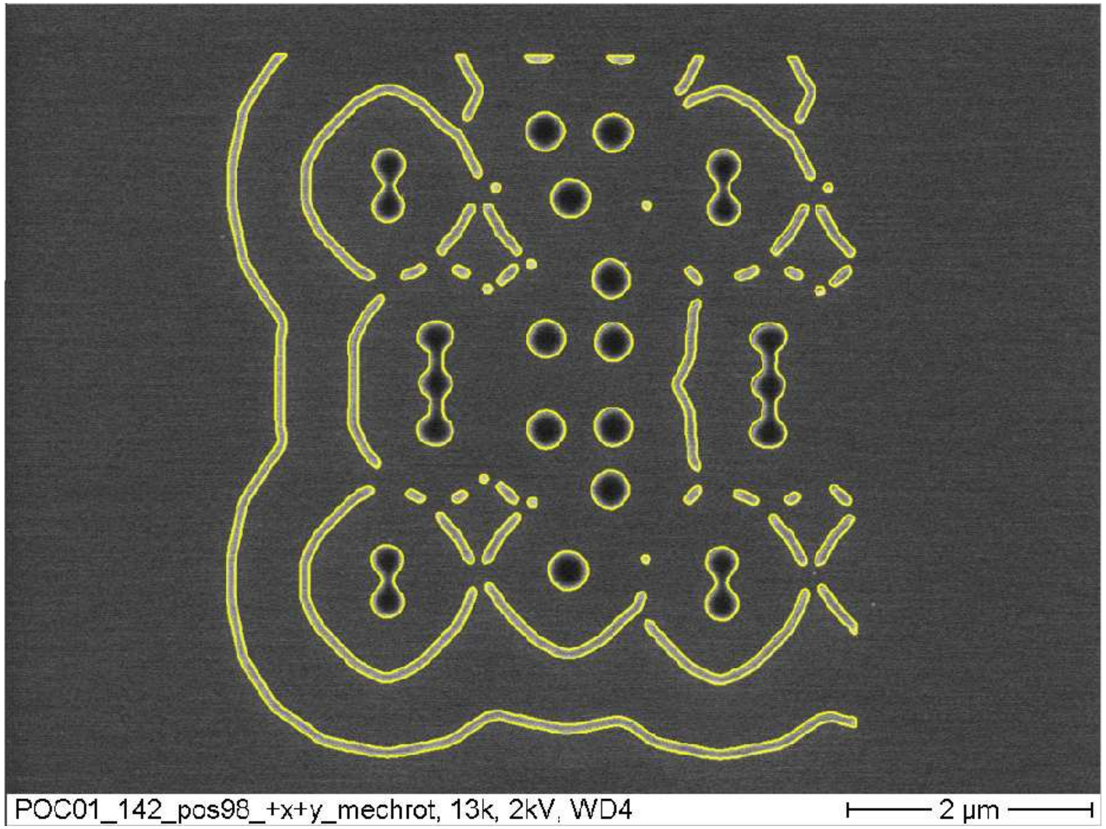


Scanning Stripe exposure of ILT device test patterns

ILT test pattern design: DNP



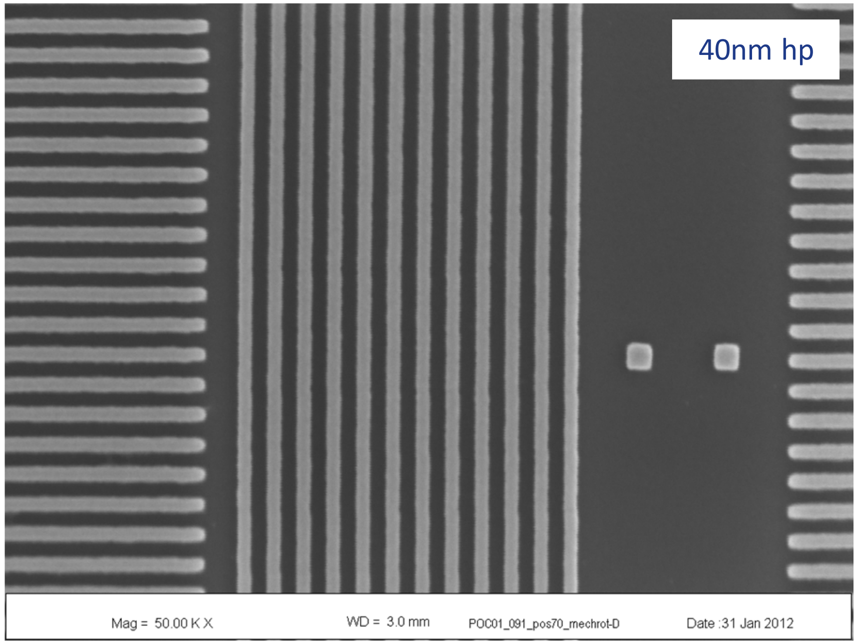
ILT: 60nm dots, 60nm lines



❒ Agreement between Design and Exposure

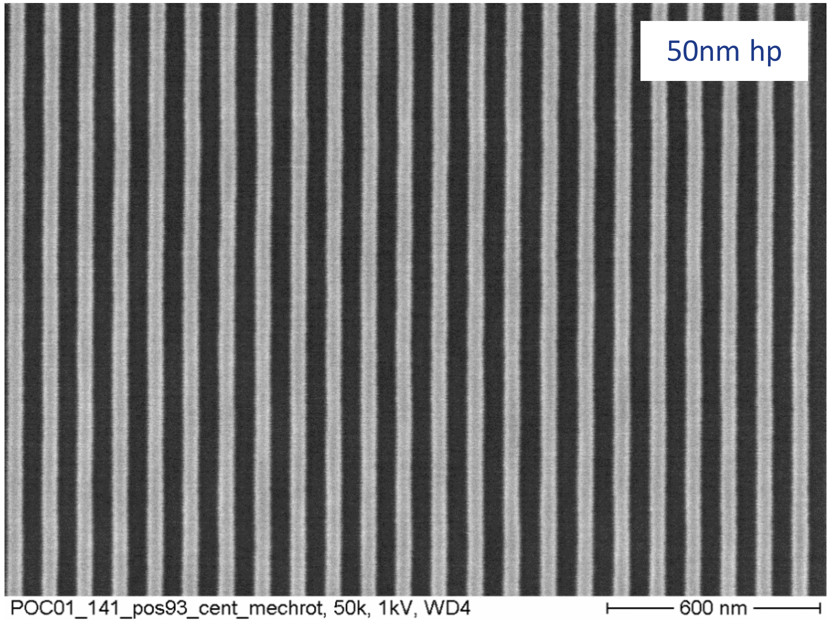
eMET POC exposure of low sensitive pCAR

HSQ
(negative non-CAR)
50nm resist thickness



Exposure Dose: 990µC/cm^2

pCAR
(positive Chemically Amplified Resist)
80nm resist thickness



Exposure Dose: **80µC/cm^2**

Summary

- Writing with 256k beams on scanning stage shown (up to 1.2mm/s)
- Demonstration of multi-beam Proximity Effect Correction (PEC) based on dose and shape corrections using gray level writing
- Prints on low sensitivity pCAR (80µC/cm²) confirm TPT capability
- Novel electron-optical column works reproducible and stable – will be used for multi generational HVM tools
- eMET Roadmap for 11nm hp node:
  - Alpha Tool in 2014 — 15h write time
  - Beta Tools in 2015 — 10h write time
  - HVM Tools in 2016 — 10h write time

$\geq$ 100µC/cm^2 resist exposure dose

eMET Roadmap

	POC	Alpha	Beta	1st gen. HVM
	2011* - 2012	2014	2015	2016
Technology Node	Test: 11nm HP (8nm Logic)	11nm HP (8nm Logic)	11nm HP (8nm Logic)	11nm HP (8nm Logic)
Beam Array Field	82µm x 82µm	82µm x 82µm	82µm x 82µm	82µm x 82µm
Current Density	0.1* - 1 A/cm^2	1 A/cm^2	4 A/cm^2	4 A/cm^2
# Beams (k=1024)	256k	256k	256k	256k
Beam Size	20nm	20nm	10nm	10nm
Max. Current	0.1* - 1 µA	1 µA	1 µA	1 µA
Throughput (≥100µC/cm^2)	> 3* - 10 cm^2/h	15h / mask	10h / mask	10h / mask

eMET Extendibility

	POC	Alpha	Beta	1st gen. HVM	2nd gen. HVM	3rd gen. HVM
	2011* - 2012	2014	2015	2016	2018	2020
Technology Node	Test: 11nm HP (8nm Logic)	11nm HP (8nm Logic)	11nm HP (8nm Logic)	11nm HP (8nm Logic)	8nm HP (6nm Logic)	6nm HP (4nm Logic)
Beam Array Field	82µm x 82µm	82µm x 82µm	82µm x 82µm	82µm x 82µm	82µm x82µm	82µm x 82µm
Current Density	0.1* - 1 A/cm^2	1 A/cm^2	4 A/cm^2	4 A/cm^2	4 A/cm^2	4 A/cm^2
# Beams (k=1024)	256k	256k	256k	256k	512k	1024k
Beam Size	20nm	20nm	10nm	10nm	7nm	5nm
Max. Current	0.1* - 1 µA	1 µA	1 µA	1 µA	1 µA	1 µA
Throughput (≥100µC/cm^2)	> 3* - 10 cm^2/h	15h / mask	10h / mask	10h / mask	10h / mask	10h / mask

Thank You for Your Attention !